

# Pennsylvania stone arch bridges: Evaluation and assessment

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**ABSTRACT:** The State of Pennsylvania enacted a plan titled “Project Keystone” in 1999, to survey, assess, and catalogue the state’s bridges in an effort to prioritize and manage such a vast and unknown historic collection. Of the three hundred eighty-six state-wide stone arch bridges that are over 6.1 meters (20 feet) long and carrying a roadway, one hundred twenty-five are located in just five of the sixty-seven state’s counties. Constructed between 1697 and 1940, the bridges in this region of the state remain in use by daily vehicular traffic.

This paper will explore the methods for which Pennsylvania tackled the survey by using a formulaic approach to assessing, cataloging, and prioritizing the stone arch bridges throughout the state. It will also present an evaluation of the qualitative nature of this large scale assessment and the impact it has made on the effort to preserve the historic bridges.

## 1 INTRODUCTION

In a state of over twelve million residents, 118849 square kilometers (45888 square miles), and over 72420 kilometers (45000 miles) of rivers and streams, the number of bridges built and remain in use by pedestrian and vehicular traffic is over 12000 (PAfact). In 1996, the Pennsylvania Department of Transportation (PennDOT) contracted with engineering firms to evaluate and catalogue all of the bridges throughout the sixty-seven counties in the state of Pennsylvania. The project later evolved into “Project Keystone,” in 1999, which evaluated the stone arch highway bridges in the Philadelphia region. The concern for public safety and aging building materials prompted this effort to evaluate all of the bridges under a multitude of criteria. The ultimate goal of this large scale survey was to create a management plan in which safety and historic preservation are integrated into the future of bridges throughout the state. The methodology used for this survey and the ultimate results are the focus of this paper.

## 2 SAFETY AND PRESERVATION

Predominately, stone arch bridges were originally constructed to pass over a small waterway and serviced only pedestrian or horse and buggy traffic. The single lane construction and limited weight capacity were not a cause for concern until the introduction of motorized vehicles. The addition of automobiles to small roadways and bridges, and the ongoing increase in vehicle sizes are contributing to the stability and ultimate safe use of the stone bridges.

In a state where there are over 3.7 million people living in rural areas, with 36421 square kilometers (9 million acres) of farmland and 55000 farms, stone arch bridges are now required to carry large farming equipment and buses for the transportation of school aged children (PAfact). The question that begs to be asked of these bridges is, if they are structurally safe to carry large motorized traffic on a regular basis. This question does not address the other safety

factors such as visibility and one lane of traffic flow. There are bridges that are arched in a manner that create visual difficulty in seeing both sides of the bridge. These bridges are a safety concern to both vehicular and pedestrian traffic. For example, if a school bus stops on one side of the bridge and allows children to get off the bus, extra precautions must be taken to not allow oncoming traffic to immediately pass the bus until the children have safely crossed in front. The same concern can also be applied to everyday car and foot traffic where a pedestrian, bicyclist, or an on-coming car can not see the approaching traffic on the other side of the bridge. In many situations, mirrors are installed so each side of the bridge can be seen. Informative road signage is also installed to tell motorists that the bridge is restricted to one lane and visibility is low.

History and the desire to preserve physical elements of the past is another driving force when considering the future of a bridge. Yet, it is easily recognized that public safety is a priority. The history of a bridge and its contributing nature to the significance and aesthetics of a local community is a valid consideration when trying to plan for the future of the structure. The state, local government and the community must decide to what degree preserving history is relevant to the bridge in question, and how safety, economy, and repair feasibility are necessary factors of their decision.

Bridges of any material, shape, or size are always limited to their use if maintenance is not factored into the equation. Stone bridges, although extremely durable, do often suffer from neglect and will eventually fail without regular maintenance. The stone is subject to erosion, salt attack, stress cracking, and mortar loss, all of which lead to a potential structural failure. The bridge is also dependant on the stability of the substructure. Over time, the foundation can be compromised by changing waterway and soil conditions from local land development. These changes can lead to spandrel walls spreading out and damaging the structure. Due to the construction of a stone bridge, its integrity relies on compressive strength. The stability of the structure can depreciate if even just a small area deteriorates. Deterioration, even if it appears minor, can lead to a total collapse.

### 3 METHODOLOGY

#### 3.1 District 6-0

An initial first campaign of evaluations was completed on the entire inventory of bridges throughout the state and a determination was made regarding which bridges were eligible to be listed on the National Register of Historic Places. From the initial survey of 12000 bridges, PennDot declared that 9000 bridges were ineligible, which left 3000 bridges open for nomination consideration. In order to determine what portion of the 3000 were truly eligible and what was already listed on the Register, PennDOT developed a team of professionals that assessed the bridges' context, materials, style, and craftsmanship. Included amongst the team were engineers from PennDOT, staff of the Pennsylvania Historical and Museum Commission (PHMC), and the Federal Highway Administration. This team of experts reviewed all 3000 bridges and the result was that just over 100 bridges were already listed on the Register, and 597 were recommended as eligible for nomination (PennDOT).

A Microsoft Access database of all 12000 bridges is available to the public and all local governing agencies. The goal for providing access to this database is that counties and townships will continue to evaluate and research their historic bridges for future planning purposes. This database can be accessed by going to: <http://www.dot.state.pa.us/Internet/Bureaus/pdCulturalResources.nsf/bridgesurvey?OpenForm>

A plan was developed to further evaluate only the stone arch bridges in a concentrated area of Pennsylvania. The Greater Philadelphia Region is comprised of five counties in the lower southeastern section of the state; Bucks, Chester, Delaware, Montgomery, and Philadelphia Counties. For management and operations purposes, this region is identified by PennDOT as engineering District 6-0. These counties contain one hundred twenty-five (current number as of November 2006) stone arch bridges, which is more than any other state in the country (Campbell, 2004). In 1999, "Project Keystone" commenced with a to determine which bridges require repair and if any needed to be totally rebuilt. PennDOT would provide the necessary

evaluation and guidance to the bridge owning jurisdiction, but would not cover all of the costs for the restoration (Campbell, 2004).

“Project Keystone” was developed by way of a concession that was made by PennDOT to develop a comprehensive plan for the preservation of stone arch bridges in District 6-0. The agreement was mandated by the US Army Corps of Engineers and coordinated with the Director of the Pennsylvania Historical and Museum Commission when an aging stone bridge was termed necessary for replacement (PennDOT, 2002). The Army Corps is responsible for the country’s waterways; therefore their orders to develop the survey program were necessary to put into immediate action. PennDOT had already developed a list of all stone arch bridges in the region, but it needed to develop a method for cataloguing the conditions and historical significance of each structure. The program would also need to create a plan to maintain bridges while preserving their historic integrity. To finalize the study, the program would also have to take into account future monitoring and repeat inspections so the information remained current and useful to the department and the public.

### *3.2 Code Definitions*

Due to financial constraints on the department for annual maintenance and systemic improvements, the survey program had to establish a numerical ranking system to identify the issues associated with each stone bridge. Seven factors were created; each assigned a numerical variable, and is as follows: 1-Condition; 2-Transportation; 3-Waterway Adequacy; 4-Development Pressure; 5-Historic Significance; 6-Rehabilitation Costs; and 7-Public Sentiment. Of these factors, three of which were adapted by the state wide Bridge Management System (BMS) that PennDOT is already responsible for maintaining (PennDOT, 2002).

### *3.3 Conditions Code*

Beginning with the Condition Code, this incorporated two values identified in the BMS, the Structural Condition Appraisal and the Scour Critical. The Structural Condition Appraisal reviews issues relative to the superstructure while the Scour Critical identifies foundation problems. The numbers assigned in the BMS are obtained from bi-annual inspections, but under federal regulations are not made available to the public. To gain a single numeric value for the Condition Code, these two BMS numbers were added together. When combined the resulting numbers range from zero to eighteen, with eighteen corresponding to the best condition (PennDOT, 2002).

### *3.4 Transportation Code*

The Transportation Code also utilized values from the BMS. This code was developed by combining six factors all relating to use, traffic, and the approaching roadway. The code contains the following factors: Bridge Operation Status, Functional Classification, Average Daily Traffic, Average Daily Truck Traffic, Deck Geometry Appraisal, and Approach Road Alignment Appraisal. Within the BMS, the first three factors were not originally identified as a numeric value but rather with a letter code. For example, the Bridge Operation Status was listed either with an “A” if bridge was open, “P” for posted, or “C” if the bridge were closed. In order to assign a numeric value, “A” is equivalent to the value five, “P” is equivalent to three and “C” equals one. This same approach was given to the descriptions provided for Functional Classification, where these were originally listed as terms of “minor collector” or “collector urban” which describes the location of the bridge and what the function of the roadway. Both Average Daily Traffic and Average Daily Truck Traffic had been listed in the BMS as a value anywhere between one and ten thousand plus. To categorize these values, a number was assigned for a range of traffic. This equates to factors such as; five equaling a range from zero to one hundred vehicles per day (VPD), and one equaling a range of 10001 and over VPD (PennDOT, 2002).

### 3.5 *Waterway Adequacy Code*

The quantification and qualification of flooding frequencies is defined by the Waterway Adequacy Code. This factor is based on a range from zero to nine, with zero being the less desired rating. Bridges effected consistently by flooding and that are frequently closed because of water overflow receive a zero. Flooding can cause considerable damage; therefore, zero ratings equate to frequent maintenance, costly repairs, and multiple inspections in order to reduce the likelihood of structural instability and failure.

### 3.6 *Development Pressure Code*

Since the state of Pennsylvania continues to grow in terms of land use and housing development, the Delaware Valley Regional Planning Commission (DVRPC) provided ratings to bridges based on their location and potential for expected frequent use. The DVRPC ranked bridges with a numeric value of one, three, or five. One is classified for a bridge located in an area with a high potential for development and within a planned growth area of the state. Three was given to bridges that were on a border of growth areas, and five identified it as outside a future planned development area. This exercise was necessary to account for future use and the potential traffic volumes that the bridge may encounter (PennDOT 2002).

### 3.7 *Historic Significance Code*

The Rehabilitation or Replacement Code was tied directly to the Historic Significance Code (also noted as the Historical, Recreational, and Cultural Values Code (PennDOT 2007). First we examine the criteria used for the Historic Significance Code. This code was developed to include three variables; one is if the bridge is listed on the National Register of Historic Places or it is eligible to be listed, the second is whether the bridge is contributing to a nominated Historic District or if it is in a park, and the third is its integrity and if the bridge has retained the architectural components necessary to be considered for future preservation (PennDOT 2002).

The values that were assigned to the National Register variable were either a five if it was already listed or a one if it was considered eligible and not already listed. If the bridge was not considered eligible when reviewed by the Pennsylvania Historical and Museum Commission, then the value was left as a zero. A similar approach was taken if the bridge was contributing to a district or located within a park. The concept with providing value for bridges in a park was that it may have a more likely chance of being restored or rehabilitated since the park system could contribute financially, and it probably receives less wear and tear from daily vehicular traffic. The values assigned to this factor were the following: five was given to bridges that were both contributing to an historic district and located in a park; if the bridge was either contributing in a district or in a park then it was assigned a three; and if neither of the previous mentioned conditions applied, then the bridge was given a one (PennDOT, 2002).

The architectural integrity rating was evaluated using the National Register's criteria for architectural significance. The definitions of architectural significance are qualified under Criterion C in the National Register's nomination application that is produced and evaluated by the nation's Secretary of the Interior and the National Park Service. The bridges were assigned values based on the total number of major parts present and intact. Parts of the bridge that were evaluated as part of this value are, but not limited to: the spandrel walls, parapets, piers, coping, pointing, weep holes, arch barrels, and wing walls. The numerical values were again one through five, with five having all of the major parts present and intact, and one was assigned where four or more parts were missing or with poor integrity (PennDOT, 2002). To clarify this point, we look at an example where the bridge would be assigned the value four because the parapet or coping was replaced with metal or concrete. Since this part was not considered missing but rather compromised because it was not replaced in kind, this bridge would be given a four. The rating for integrity would then be added to the eligibility and district ratings to form the Historic Significance Code.

### 3.8 Rehabilitation Code

As previously mentioned, the Rehabilitation Code was coordinated with the Historic Significance Code. The Rehabilitation Code utilized a formula where the integrity rating is multiplied by rough costs per foot.

$$\text{Cost} = (6 - \text{IR}) * (\log_{10} (L * W))$$

where: IR=Integrity Rating, L = length in feet, and W = width in feet.

The log, base 10, was determined necessary in the formula so the length and width of the bridge would not be the primary factors in the resulting calculation. For example, a bridge that is 30.5 meters (100 feet) long will cost much more than one that is only 6.1 meters (20 feet) in length. By multiplying it by the log, the length and width values are included in the result but their impact is diminished. Once this formula was calculated for each bridge, the cost was multiplied by a constant of € 90737.50 (\$120000). This constant did not include costs such as design fees, but rather just raw construction costs. The net result provided the value for the Rehabilitation Code (PennDOT, 2006).

### 3.9 Public Sentiment Code

Lastly, the Public Sentiment Code, or later termed Public Input Code, was developed by making available public survey forms to residents of the region and holding stakeholder and local government meetings. The forms were available online so interested parties could participate. Public input is an evolving variable since news of the results and the plan are being learned throughout the community, and responses submitted to PennDOT for consideration continue after the information is made public. The survey form informed the public that the answers provided by the participant were being evaluated as part a Bridge Management Plan, and that the goal of the plan was to develop an approach to assess and plan preservation efforts for stone arch bridges in District 6-0.

Some of the questions asked on the survey form included; “Is there a stone arch bridge on your travel route and if so, how often do you drive across;” and, “If a stone arch bridge could no longer handle the volume or weight of modern day traffic and would need to be closed or replaced, what action would you prefer?”.... “1 – Demolish the bridge and replace it with a modern bridge structure (lowest cost option); 2 – Close the bridge to vehicular traffic and maintain it for pedestrian use (address any remaining transportation needs in other ways); 3 – Dismantle the bridge and give the stones to the community for its choice of re-use (e.g. placement in a park, reconstruction as a pedestrian bridge, etc.) then replace the bridge with a modern bridge structure; 4 – Dismantle the bridge and give the stone to the community for its choice of re-use, then replace the bridge with a modern structure that has the appearance of an historic bridge (stone façade)” (PennDOT,2002).

These questionnaires were then evaluated with any other correspondence that was received by PennDOT and given a numerical value for the Public Input Code. The values assigned were numbered one through five, according to the following criteria: five was given to a bridge where there is a designated organization whose charge is to preserve and maintain the structure or an elected body has mandated its preservation; a four was given when an organization had expressed interest or it was mentioned more than twenty times in the survey forms; three if it was noted in the forms between five and twenty times; two if it was reported between one and five times; and a one was assigned when the bridge was not noted or if it had received a negative response in the forms.

### 3.10 Standardization

Once factors for each code were calculated, standardization was necessary in order to compare like integers and create equality amongst the codes. Since each code had a varying number of variables, standardization was developed by “subtracting the mean of the total code type for all bridges from the value for the particular bridge, then dividing it by the standard

deviation of the total code type” (PennDOT 2002). Since this formula may produce a negative number, the result was then added by five, and then multiplied by a factor ten. This calculation then produced numbers that ranged from one to one hundred, and could be interpreted as percentages. Having data within this scale was not mathematically necessary but rather more readily understood by the evaluators who do not regularly deal with statistical analysis (PennDOT 2006). Once each code was standardized they were summed to form the total score for the bridge.

#### 4 RESULTS

The computation of the codes were collected and sent for review by an expert panel including, representatives from PennDOT’s District 6-0, the department’s Central Office, and a member from the Federal Highway Administration. The review consisted of an evaluation of the code rankings and long term preservation needs for the bridges. The definition of long term preservation was defined to mean the commitment to a “bridge for a period of twenty-five to thirty years. Depending on factors such as the materials used to construct the bridge, the care and maintenance it previously received, and present and future structural and traffic conditions, recommending a bridge for long-term preservation could mean that a bridge will have a lifespan that extends beyond twenty-five to thirty years” (PennDOT, 2007).

After the results were tabulated and indexed according to rank and bridge number, the draft of “The Stone Arch Bridge Management Plan,” was fully realized. The draft incorporates the methodology used to assess the bridges and the preliminary recommendations based on the code scores. The plan incorporates these recommendations and provides basic information for what the future of each bridge should be, whether it be preserved or replaced. The goal of the plan was to ensure that bridges with historic value not be destroyed or damaged in any way. The emphasis is given to regular maintenance and how this is the best course of action to ensure the preservation of the bridges (PennDOT, 2007).

Also included in the drafted plan are preliminary recommendations for additional measures that can be taken to enhance the safety of the stone arch bridges and potentially prolong their lifespan. The plan mentions that better signage is imperative and that improving the alignment and roadway approaches will better protect the general wear and tear of the bridges and contribute to vehicular and pedestrian safety. Working with the Delaware Valley Planning Commission is also necessary to address development and planned growth. If development throughout the region could take into the account the existing stone bridges and their use in the community, functionally, aesthetically, and historically; then roadways can be designed to limit daily traffic. Another recommendation in the plan is to recognize that there are context-sensitive solutions for replacement options when an understanding is reached that a bridge must be altered. PennDOT realized that when these bridges present historically sensitive issues, that the outcome of the bridge will have to be made collaboratively with the community, partnering agencies, and other stakeholders (PennDOT 2007).

When completed, the survey totaled more than sixty bridges that should be considered for long-term preservation. This total roughly represents forty-eight percent of the total bridges surveyed. While direct approaches to how the bridges should be preserved or maintained are suggested in the draft plan, PennDOT has not given recommendations to non-PennDOT owned bridges. Bridges that are owned by local municipalities or organizations are provided with the ranking codes established by the survey, but recommendations are not included since the department did want to impress upon the owners their interpretation of what the fate of the bridge should be (PennDOT, 2006).

Goals for preserving stone arch bridges will require additional funding sources. The department is currently reviewing the drafted plan and identifying potential financial opportunities to facilitate the plan. Ultimately, the final results and adopted management plan will then be incorporated and coordinated with PennDOT’s Transportation Improvement Program (TIP) for statewide maintenance planning and procedural updates (PennDOT, 2007).

#### 4.1 Analysis of the Results

The assessment and the drafted “Stone Arch Bridge Management Plan” aimed and achieved a method for quantifying the potential needs of stone arch bridges in District 6-0 of Pennsylvania. The formulaic approach used to assess the bridges was fairly inclusive to factor in not just structural conditions, but also historic integrity, traffic use, development potential, and rehabilitation feasibility. While the draft plan is still under review by governing officials, the draft and database results are available to the public on the internet. As public interest has grown and there is recognition that it is the responsibility of the state to report progress, the amount of available online information is reasonably complete. Mapping of the bridges and general evaluation sheets, along with a photograph of each bridge is available for public review. The online map indicating the bridge locations is interactive and allows the viewer to selectively obtain information about a particular bridge by merely picking a point on the map (fig. 1).

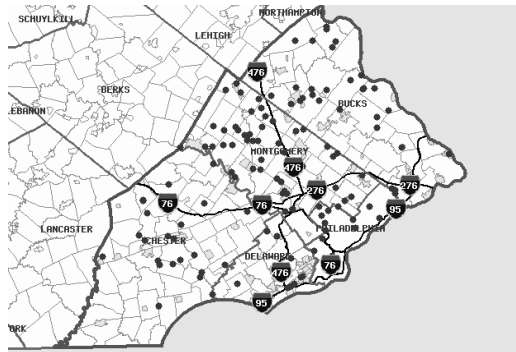


Figure 1: Map of District 6-0 with markers indicating bridge locations (PennDOT).

The available evaluation sheets on the bridges provide basic information on the bridge name, location, roadway in which it carries, the type of construction, and the overall dimensions. The sheets also supply the year the bridge was constructed and any subsequent dates for major alterations or reconstructions. The historical status is also noted, with whether the bridge is eligible for nomination to the National Register of Historic Places, and if it is contributing to a park or historic district. One view of the bridge is provided in a photograph, and the location map can be magnified to show major street intersections adjacent to the bridge (fig. 2).



Figure 2: Photograph of Center Street Bridge, Newtown, PA. Constructed 1796, altered in 1875 (PennDOT).

What is not included in the evaluation form at this time is the ranking values that were developed and calculated for each bridge. These values are included in the draft plan, along with a statement of the preliminary recommendations. The recommendations, even if

preliminary, are useful to the public because they can provide the basis for which fundraising efforts could begin, even if it is just on an organizing grassroots level. For example, the remarks provided for an 1884 bridge in Carversville (no. 7) note that the bridge is not eligible for an individual listing, but that it does contribute to the Carversville historic district. When this same bridge is referenced in the draft plan, the preliminary recommendation is for long-term preservation. Preservation is recommended for this bridge because it was recently reconstructed and is in area ranked with a low potential for added growth with low traffic volumes. It also reports that the community responded by completing twenty-six questionnaires, three letters, and five emails in favor of maintaining the bridge. Once all of this information is included in the bridge evaluation forms, this information is made publicly available and can be distributed to help in the future planning and organization within the community and its local government for its maintenance and ongoing preservation. Along these same lines, providing the public with additional photographic records of the bridges is useful in tracking the conditions and the rate at which materials deteriorate. Providing these photos would not be in lieu of regular inspections and photographing by PennDOT, but rather give the interested public some sense of participation and contribution. Condition photos taken over a period time can be a powerful tool when seeking funds for historic preservation.

Although there are strengths to the code rankings, there are several flaws with the basic process. For instance, there is no allotment for safety in the ranking process, in terms of reported accidents and high speed travel, either on or around the bridges. The condition code only deals with safety, with regard to structural stability of the bridge. The transportation code only provides a value for average daily traffic flow and does not include values for peak flow or high speed travel rates. If the draft plan goes so far as to consider signage, roadway abutment, and alignment issues, then the formula to rank the bridge should also include a value for reported accidents. Without the knowledge of past vehicular accidents and the frequency of which they have occurred, it is difficult to imagine that the final ranking of the bridge truly represents the needs and demands of the community it serves.

When reviewing the code formulation for Public Input, it was ultimately the quantity of the responses over the quality of what was reported which ultimately defined the numeric value for the code. For example, a more compelling response toward the preservation of a bridge may be made by an interested party, but if this was the only response made to PennDOT, the ranking for this code would still remain low in comparison to another bridge which may have had more responses due to better organization amongst its community. The lengthy form used to collect opinions from the public was only measured statistically, but the form also offered entry for handwritten essay responses and not a controlled set of just “yes or no” or the check the box answers. The form itself is generally cumbersome and asks the participant to write-in over ten essay responses. Although the write-in responses and comments are included in the draft plan as a matter of record, these ultimately go unaccounted for in the final ranking process as there is no way to quantify the various narrative answers within the code formulas.

The method for which the bridges were evaluated in the Historic Significance Code is a harsh and superficially simplistic way in which to evaluate their importance. It is well understood that public money must be spent wisely but simplifying the process to a rating scale of five variables is extremely difficult. The use of just reviewing the bridges under Criterion C in the National Register nomination process limits the reviewer to consider historical relevance based on significant events and people in our history. The distinction between what was eligible for individual listing and what is included in a park or historic district should not have been given two unequal values. The logic that a stone arch bridge is less important because it is not eligible because it only contributes to an historic district is arguably flawed since a structure that contributes to a district would diminish the district if it were replaced or drastically altered. These two values should have been combined into one factor, even if the preservation review and approval process by the local jurisdiction would vary.

## 5 CONCLUSION

The assessment conducted by the State of Pennsylvania’s Department of Transportation has provided a great service by recognizing the need to evaluate and identify stone arch bridges that



require both immediate and long term preservation care. Collections management is the key to understanding and planning for the future of these stone arch bridges in the Philadelphia region. What was learned from this exercise is that over half of the bridges that are managed by the state are historically significant and integral to the regions aesthetics, development, and community pride. This formulaic assessment is a practical approach to establishing critical factors and assigning values that could be standardized and compared equally. This study has tried to tackle the problem of humanizing the statistics by inserting variables for public input and sentiment, but the ultimate quantification of this element does not add anything meaningful to the final ranking.

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